Before the

FEDERAL COMMUNICATIONS COMMISSION

Washington, D.C. 20554

In the Matter of	)	
	)	
Amendment of the Commission's Rules to Permit Radiolocation Operations in the 77-81 GHz Band.	)	**WT Docket No. 11-202**
	)	
Request by the Trex Enterprises Corporation for Waiver of Section 90.103(b) of the Commission's Rules	)	**RM-11612**

To: The Commission
Via: Office of the Secretary

COMMENTS OF ROBERT BOSCH, GmbH

Robert Bosch, GmbH (Bosch), by and through counsel and pursuant to the *Notice of Proposed Rule Making and Order*, FCC 11-185, 77 Fed. Reg. 1661 released in this proceeding December 20, 2011 (the *Notice*), hereby respectfully submits its comments[1] in response to the issues raised in the *Notice*. The *Notice* proposal was developed in response to the Petition for Rule Making filed by Trex Enterprises Corporation (Trex), seeking amendment of the Commission's Part 90 rules to permit 78-81 GHz Foreign Object Debris (FOD) radars at airports on a licensed basis. It is asserted that these FOD radars will improve airport safety and minimize possible instances of collision of aircraft on airport runways with objects on the runway.[2] Bosch interposes no objection to the

[1] These comments are timely filed pursuant to Section 1.415 of the Commission's Rules, 47 C.F.R. § 1.415, as they are being tendered within thirty (30) days of the January 11, 2012 date of publication of the *Notice* in the Federal Register.

[2] The Commission has granted the waiver of Section 90.103 of the Commission's Rules as requested by Trex to permit certification, manufacture, licensing and use of its FOD detection radar equipment, pending the resolution of its Petition for Rulemaking (RM-11612) in this proceeding. Bosch takes no issue with this waiver grant, but urges that any licenses for use of the FOD radars issued pursuant to the waiver but prior to the ultimate resolution of this Docket proceeding be made contingent on the outcome of (1) the Docket

Commission's proposal *per se*. However, Bosch urges the Commission to take no action in this proceeding which would hinder or preclude the rollout of short-range automotive radars (SRR) in the 77-81 GHz band in the United States. Bosch strongly urges that *unlicensed* operation of FOD radars at airports should not be permitted for several reasons, and that the Commission should not resolve this docket proceeding without the benefit of technical showings, cooperatively prepared by the stakeholders in this proceeding, as to the electromagnetic compatibility between mobile FOD radar systems at airports, automotive SRR radars at 77-81 GHz, Radioastronomy (RAS), and the Amateur Service. Such showings are necessary in order to ascertain the necessary operating parameters and license conditions for FOD radar systems, so as to insure compatibility with other incumbent and future services in that band. It is unclear at present whether the technical parameters for FOD specified in the waiver grant[3] are sufficient to protect automotive radar systems operating on public roadways near airports, and therefore what, if any, preclusive effect would result from authorizing FOD radars sited at airports in this band. For its comments, Bosch states as follows:

I. Introduction.

1. Bosch is a multinational corporation which manufactures many different types of high-quality products for numerous industries, including vehicular radar systems and automotive components and systems. Bosch is active in establishment of international standards for automotive radar systems, anti-collision systems, and automatic braking

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proceeding, and (2) compatibility studies relative to the effects of FOD airport radar systems on automotive short-range radar systems at 77-81 GHz, which should be conducted prior to any permanent, licensed deployment of FOD radars at airports. As will be seen below, Bosch requests that the Commission withhold final action in this proceeding pending the conduct and publication of these studies as part of the relief granted in this proceeding.

[3] See Paragraph 18 of the Notice; these parameters include transmit power of 100 mW; Antenna Gain of 45 dBi; System EIRP of 35 dBw; Vertical Transmit polarization with a beamwidth of (3 dB) 1 deg (el) X 0.2 deg (az) and an FMCW chirp repetition rate of 139.5 Hz.

systems. Bosch manufactures long-range automotive radar systems for vehicles in the 76-77 GHz range and short-range automotive radar systems to operate at 77-81 GHz. SRR automotive systems are now permitted in Europe and in many countries other than the United States. Bosch has a distinct interest in the effective performance of these safety-of-life systems in motor vehicles in the United States and in their reliable performance, on which motor vehicle operators and passengers rely for their safety.

2. There is presently a worldwide plan to consolidate automotive radars in the 76-81 GHz band.[4] CEPT has concluded that the so-called “79 GHz” band should be the only globally harmonized frequency band for automotive radars.[5] As stated in the Notice in this proceeding, long-range automotive radars now operate in the United States at 76-77 GHz pursuant to Section 15.253 of the Commission’s Rules. However, that band is used only for medium and long-range (i.e. vehicle and infrastructure radar systems) radars. Sharing studies conducted by the automotive industry have concluded that sharing between SRRs and long-range automotive radars is not possible. It is firmly settled that the 79 GHz frequency range (i.e. 77-81 GHz) should be considered as the most suitable band for SRRs.[6] Indeed, the Commission has repeatedly acknowledged this for many

[4] The 77-81 GHz band was designated by the European Conference of Postal and Telecommunications Administrations (CEPT) as early as July 2004 for automotive radar. The European Commission has adopted the decision 2004/545/EC on the harmonization of radio spectrum in the 79 GHz range for the use of automotive radar. The harmonized standard EN 302 264 has been adopted by ETSI for short-range radar (SRR) operating in the 77-81 GHz band. In March of 2010, the Ministry of Internal Affairs and Communications (MIC) in Japan has started a study group in the info-Communications Council for the introduction of high-resolution radar in the 77-81 GHz frequency band. In October of 2010, the State Radio Frequency Committee of Russia allocated the 77-81 GHz band for automotive radar.

[5] There is ongoing now the “79 GHz Project”, an international automotive 79 GHz frequency harmonization initiative and worldwide operating vehicular radar frequency standardization platform. See, www.79ghz.eu. This project, among other things, tracks the progress of allocation of the 77-81 GHz band in various countries relative to automotive radar systems. At the outset of the project, 79 GHz radar equipment was authorized in 27 EC member states; most of the 21 CEPT countries; and Singapore and Australia.

[6] Sharing with the Radioastronomy Service has been studied in Europe and in the United States. The European studies concluded (and the United States studies confirmed) that regulatory measures can be

years.[7] Bosch has notified the Commission's Office of Engineering and Technology that it intends to submit in the near term a Petition for Rule Making proposing the modification of Section 15.253 of the Commission's rules to permit the operation of automotive SRRs in the 77-81 GHz band in addition to the present 76-77 GHz band now permitted by that rule Section.

3. The value of automotive radar systems to the public as safety-of-life devices is beyond question, and the statistics supporting that are highly compelling. The Commission stated in 2002, when first permitting short-range vehicular radars at 24 GHz that it expected "vehicular radar to become as essential to passenger safety as air bags for motor vehicles…"[8] This prediction has largely been validated since that time. Automotive radar systems have been proven to substantially reduce injuries and death due to automobile collisions.[9] The National Highway Traffic Safety Administration

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developed enabling coexistence between SRRs in the frequency band 77-81 GHz and the Radioastronomy Service.

[7] For example, in Docket 03-102, resolved in 2004, the Commission adopted domestically the RAS and space research service allocations in the 77-81 GHz band. The Commission refused to withhold the domestic implementation of the RAS and space research allocations due to possible future use by vehicular radar systems, although the Commission "recognize(d) that there [was] a great deal of ongoing international discussion about the current and future spectrum needs of SRR systems" in that band. The Commission at the time denied a request filed by Delphi Corporation to initiate a proceeding to establish rules to allow vehicular radar operations in the 77-81 GHz segment. However, the Commission invited proposals in the future for such use. The Commission said that "entities may file petitions for rule making requesting the Commission to take such action. Such petitions should include specific proposals for technical and other rules."

[8] *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, First Report and Order, ET Docket 98-153, released April 22, 2002, at ¶ 18.

[9] Various studies on the safety benefit of automotive safety systems have been published. At the 21st International Technical Conference on the Enhanced Safety of Vehicles, Stuttgart, held in June of 2009 (www.esv2009.com), the following studies were presented:

(A) Daimler provided a study that showed that with its Brake Assist Plus (collision warning and partial braking) it is possible to prevent 53% of all rear-end collisions that otherwise cause injuries. To support this figure, a comparison of repair parts statistics of cars with and without radar-based functions was made. It could be clearly determined that at speed between 14 and 50 km/h could be reduced by 22%. It was also shown that the impact speed of collisions was reduced (e.g. impact speed between 14 and 45 km/h by 38%). In sum, crashes could be avoided or at least the impact speed can be reduced significantly.

(B) The Swedish Road Administration (SRA) published a study that reduction of collision impact speed by 10% would reduce the risk of fatalities by 30%.

(NHTSA) determined that the number one cause of death in persons aged 4 to 34[10] during 2005 were multiple vehicle traffic crashes.[11] According to a Honda study in 2005, the use of its collision mitigation braking systems reduces the number of rear-end collisions by 38% and the number of fatal rear-end collisions by 44%. Bosch completed a 2009 study which concluded that emergency braking assist technology will reduce personal-injury rear-end collisions by 39%; and that automatic emergency braking will reduce personal-injury rear-end collisions by 74%. The Insurance Institute of Highway Safety completed a 2010 study of the effects of forward collision warning radar systems on passenger car collisions. The study found that 20 percent (i.e. 1.2 *million*) of passenger car collisions can be avoided by the use of forward collision radars; 9% (i.e. 66,000) of accidents with injuries can be prevented by such use; and 3% (i.e. 879) of fatal accidents can be prevented by such use. Daimler made a presentation to the World Automotive Congress in September of 2008, reporting on a study of 66,000 real accidents, using the German In-Depth Accident Study database. The study was limited to analysis of rear-end collisions. The study concluded that 20 percent of all rear end crashes could have been avoided if the cars had been equipped with short-range radar-based intelligent brake assistance. Even in cases when the crash was unavoidable the reduction of crash energy was

(C) The German Insurers Accident Research (UDV) stated that autonomous partial braking could avoid 12% of all accidents. Systems with autonomous emergency (full) braking could avoid 40% of all kinds of collisions.

[10] The age groups in this study between ages 4 and 34 included young children (4-7), children (8-15), teens (16-20), young adults (21-24) and other adults (25-34).

[11] *See* National Highway Traffic Safety Administration, "Evaluation of an Automotive Rear-End Collision Avoidance System, DOT HS 810 569 (March 2006) *available at:* http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2006/HS910569.pdf.

significant and the severity of the crash consequences would have been mitigated in 25 percent of the accidents.[12]

4. However, to date, the availability of these life-saving and injury-preventing technologies has been limited in the United States to equipment integrated into more high-end passenger vehicles due to the absence of an internationally harmonized standard for SRRs.[13] A worldwide allocation (or regulatory authorization under Part 15) would be beneficial in terms of efficient use of spectrum as well as in the economies of scale that would encourage substantial rollout of SRR technology in a *much* wider range of passenger vehicles.

5. Bosch does not question the Commission's tentative conclusion in the Notice that FOD radars operating at airports would be valuable, safety-related facilities [14] and it is not suggested that there cannot be compatible sharing between licensed FOD radars at airports and automotive SRRs on motor vehicles, even in close proximity to FOD-equipped airports. However, because of the importance of SRRs nationwide to motor vehicle safety on roadways *throughout* the United States, it is important to authorize FOD radars in such a way as to minimize the potential for interaction between FOD radars and automotive radars in the 78-81 GHz portion of the 77-81 GHz band. Motor vehicle operators and passengers must be entitled to rely on the effective performance of these

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[12] See also Schittenhelm, Dr. Helmut., *Design of Effective Collision Mitigation Systems and Prediction of Their Statistical Efficiency to Avoid or Mitigate Real World Accidents* (Daimler AG), 14 September 2008.

[13] However, *see* ITU-R Preliminary Draft Recommendation ITU-R M.1452-1 (Question ITU-R 205-4/5) Regarding Millimeter-Wave Automotive Radars and Radiocommunication Systems for Intelligent Transport System Applications. This recommendation provides system requirements, technical and operational characteristics of millimeter-wave ITS applications at 76-77 GHz and 77-81 GHz. (See especially Annex 2 thereto).

[14] Bosch certainly does not dispute the finding of the Federal Aviation Administration that FOD "poses a significant threat to the safety of air travel."

systems without geographic limitations. Bosch suggests that this can be done by prudent siting of FOD radars through the licensing process.

II. The *Notice* Proposal.

6. The *Notice* does not propose the operation of FOD radars below 78 GHz. The 78-81 GHz band is allocated domestically on a primary basis for radioastronomy and radiolocation. Secondarily, the band is allocated to the amateur and amateur-satellite services and space research downlinks (space-to-Earth). There would be no changes necessary to the Table of Allocations in order to permit either FOD radars at 78-81 GHz or automotive radars at 77-81 GHz. As noted above, automotive radars now operate in the United States in the 76-77 GHz band pursuant to Section 15.253 of the Commission's Rules on an unlicensed basis. Trex proposed in RM-11612 and the Commission now proposes in the *Notice* to amend Section 90.103 of the land mobile service rules to include the 78-81 GHz band in the Radiolocation Service Frequency Table among other bands available for mobile radiolocation. However, the Commission's proposed Footnote 30 to the Radiolocation Service Frequency Table would limit eligibility for licensing at 78-81 GHz to airport authorities or entities approved by FAA. The Footnote would also limit licensed radiolocation use of the band to "foreign object debris detection." This assignment limitation is intended to protect millimeter-wave Radioastronomy observatories from potential interference. It is not intended to be sufficient to protect future automotive radar use in the 78-81 GHz band. The Commission, at Paragraph 14 of the *Notice*, asks for comment on the operating parameters that are necessary for FOD radars. It notes that there are currently *no specific power limits, bandwidth limitations, or frequency stability requirements for radiolocation operations in the 78-81 GHz band*.

7. As a counterpoint to the specificity of the Appendix to the *Notice* proposal, the Commission does ask some important, but far more general questions in the *Notice* concerning the 78-81 GHz band. At paragraph 6 of the Notice, the Commission asks whether or not, in addition to its proposal to amend its Part 90 rules to permit FOD detection at airports, it should also propose to amend the same Part 90 rules to permit radiolocation use of the band "for any other conforming radiolocation use." It also asks what the "cost" of the proposed Part 90 change to permit FOD radars or other conforming radiolocation uses would be, in terms of preclusion of other uses of the same spectrum.

8. Finally, at Paragraph 7 of the *Notice*, the Commission expresses concern that limiting use of the 78-81 GHz band to use by FOD radars solely on a licensed basis could frustrate future opportunities for additional systems with safety-related applications to use the band. Specifically, the Commission notes the operation of SRRs in Europe [citing ECC/DEC/(04)03] and cites the commitment of the National Telecommunications and Information Administration (NTIA) to "work with the Commission to ensure that an adequate frequency allocation in the 77-81 GHz band is available for the operation of vehicular radar systems."[15] The Commission notes that SRR is likely to be authorized on an unlicensed basis, as is the case with other automotive radars operating at 76-77 GHz.

III. FOD Radars Should Be Permitted at 78-81 GHz On a Licensed Basis With Certain Operating Restrictions Necessary to Protect Future Automotive Short Range Radars at 77-81 GHz.

9. It is recognized that there is a high degree of frequency re-use in the 78-81 GHz band, due to (1) propagation losses, and (2) the use of high-gain, narrow-beamwidth

[15] Comments of NTIA in ET Docket No. 98-153, at 22-23 (filed January 15, 2004), cited at footnote 12 of the *Notice*.

antennas. That said, however, SRRs in the 77-81 GHz band (which as a practical matter[16] must be operated as an unlicensed device), radiate in multiple directions from a motor vehicle and require a certain degree of interference protection in order to function adequately. If FOD radars at airports utilize directional antennas, aimed in a generally downward direction toward an airport runway, that configuration, despite the mounting of the radar on a motorized vehicle moving the FOD radar back and forth along airport runways, will likely minimize interference on public roadways adjacent to airports. The operating configuration of the radar, coupled with the limited propagation characteristics of the 77-81 GHz band, could provide sufficient protection for SRR operation in the 78-81 GHz band. Bosch suggests therefore that it is possible that FOD radars, depending on the operating parameters contained in the Part 90 rules, could avoid interaction with SRR-equipped motor vehicles on roadways near airports, and without adverse interaction with the few millimeter-wave Radioastronomy observatories in the United States. As is discussed below, however, the proposed modification of Section 90.103 of the Rules set forth in the Appendix to the *Notice* is not currently sufficient to insure compatibility with other uses of the 78-81 GHz band.[17]

10. There is <u>no</u> doubt but that FOD radars must be operated on a licensed basis. There are two principal reasons for this. First, the Commission's Part 15 rules do not typically address siting issues. Regulation of unlicensed RF devices normally does not include restrictions on installation configurations. Instead, (with but very few

[16] The devices operate in large numbers of privately owned motor vehicles and they are mobile, itinerant and ubiquitous.

[17] The Commission notes this at Paragraph 14 of the *Notice*, in that it asks for comment on the operating parameters that are necessary for FOD radars. It notes that there are currently no specific power limits, bandwidth limitations, or frequency stability requirements for radiolocation operations in the 78-81 GHz band.

exceptions)[18] they simply limit field strength or the characteristics of the device itself, not where and how the device is to be used *in situ*. Regulation of siting of an RF device (and the enforcement of that regulation) is more appropriately addressed in the licensing process. In this case, the interference potential of FOD radars may depend on the location of the radar on a mounted vehicle on the airport property near a runway. An appropriate licensing condition for the FOD radar might be that the radar must be mounted and utilized so that when in use it does not, within the main beamwidth of the antenna (azimuth or elevation), illuminate a public roadway near the airport.[19]

11. The second reason why 78-81 GHz FOD radars must be licensed is that there is no effective way to address interference after-the-fact or incorporate eligibility or use restrictions on operation of unlicensed FOD radars. It is readily apparent that the Commission lacks the resources to effectively enforce Part 15 rules in most cases, and so the interference must be addressed *ex ante*. Without licensing, the ability of the Commission to address interference problems on a case-by-case basis is lacking. More to the point, as all parties seem to agree, FOD radars are indeed safety-of-life systems, and licensing them provides the necessary interference protection.

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[18] Although the Commission has authorized 433 MHz RFID systems to operate on an unlicensed basis with a geographic area and use limitations (use was limited to commercial and industrial areas only, and such systems could operate only for the purpose of tracking commercial packages), it did not impose that limitation in a vacuum. Rather, it also imposed a requirement that the manufacturer of the RFID devices keep records of the purchaser and the locations of operation of the systems.

[19] This condition was appropriately suggested by Era Systems Corporation ("Era") in a proposal being addressed in ET Docket 11-90 to permit fixed use of 76-77 GHz radars at airports for monitoring terrestrial vehicle movement. Era (recognizing the need to protect what in that band are incumbent SRRs in the United States) noted that an essential component of its waiver request and proposed permanent authorization for fixed radar installations would be to ensure that no roads accessible by motor vehicles would be illuminated by the radars. While SRRs are not now incumbent uses at 78-81 GHz, and while the Era radars are fixed rather than mobile, unlike the Trex FOD radars, the Trex radars would operate mobile only in a limited area and could in the licensing process certify that the installations would not illuminate public roadways.

12. On November 21, 2011, NTIA sent to the Chief, Office of Engineering and Technology a letter forwarding the concerns of the FAA with respect to FOD radars and other uses under consideration for unlicensed operation at airports for, or in support of safety operations. FAA, which has examined this issue in detail, in a letter to NTIA's Office of Spectrum Management, noted that FAA supported the authorization of FOD radars, but *only* on a licensed basis. It stated that "[a] practical measure would be demonstrated assurance that FOD radars and other systems (licensed or non-licensed) can operate compatibly in the same spectrum." Specifically with respect to the compatibility between FOD radars and automotive radars in the 78-81 GHz band, FAA stated: [20]

> A question was raised about FOD radars if they share the spectrum with vehicular collision avoidance radars, which now operate on a non-licensed, non-interference basis (NIB). Specifically, what would be the FAA's position if vehicular radars were elevated to primary status? Automotive radars on an NIB potentially present operational challenges and regulatory problems if interference to either system occurs. Neither safety service (assuming that vehicular radars are considered safety systems) shall accept interference; hence, primary status becomes a challenge. Regulatory status alone does not assure compatibility. Compatibility will have to be designed into both systems.

Bosch agrees with FAA's assessment. On the one hand, it would be anomalous in Commission jurisprudence to suggest that a licensed mobile radio service operating in accordance with a primary allocation in the Table of Allocations should be subject to rules in Part 90 to limit in the licensing process the interference potential to Part 15 unlicensed vehicular radars which have not yet been authorized in the band. However, as discussed above, the Commission is well-aware of the ongoing worldwide harmonization of automotive radar use of the 76-81 GHz band, and it has specifically asked in the *Notice* what the preclusive effect would be of authorizing Part 90 operation by FOD

[20] FAA Spectrum Engineering Services Letter to NTIA Office of Spectrum Management dated October 13, 2011 (emphasis in original).

radars. If the rules governing FOD radars are not carefully designed, then as FAA notes there could be a very significant preclusive effect on automotive SRRs, and a very significant adverse effect on vehicular safety.

13. FAA further states that any unlicensed FOD radars would be unusable by the FAA. It is readily apparent that, in order for these devices to be suitable for FAA-controlled airports, they must be licensed. That is feasible given the number of such radar systems that could be deployed at airports around the country. It is not, however, sufficient by itself to insure compatibility with aeronautical radar systems. Bosch proposes that cooperative tests be conducted to determine the potential interaction between FOD radars and automotive radar systems, thus to determine the necessary power, antenna, bandwidth and emission limits that are appropriate for FOD radar systems and to minimize any preclusive effect of authorizing these radars.[21] Bosch has recently participated in cooperative testing of the potential interaction between automotive radar systems and millimeter-wave Radioastronomy observatories, and the results of those studies are now public.[22] Similar testing should be done before final action is taken in this proceeding to determine the compatibility between FOD radars and automotive radars, and to the extent the Commission deems necessary, between FOD radars, Radioastronomy millimeter-wave observatories and Amateur Radio facilities.[23] These tests will also permit ascertainment of the proper power and antenna limitations,

[21] It would appear that no such studies have heretofore been conducted. Indeed, in an ECC Report (#56) entitled *"Compatibility of Automotive Collision Warning Short Range Radar Operating at 79 GHz with Radiocommunication Services"* (Stockholm, October, 2004) it was stated that: "*NATO informed the CEPT that there are no radiolocation systems operational in the 79 GHz frequency range and that there are currently no plans to introduce such systems. No compatibility studies were therefore conducted with radiolocation systems in this frequency range*."

[22] A copy of the test results and conclusions are attached hereto as ***Exhibit A*** for reference.

[23] Bosch has also been engaged during the past year or more in cooperative discussions with ARRL, the National Association of Amateur Radio Operators, regarding compatible use of the 77.5-81 GHz band by SRRs and Amateur Radio stations.

emission types, bandwidth limitations, emission mask and frequency stability of the FOD radars.

14. Under no circumstances whatsoever should the Commission permit radiolocation devices generally under Part 15 or Part 90. Unspecified radiolocation operation will completely preclude automotive radars at 77-81 GHz. This is because it will be impossible to coordinate any automotive radar operation with radiolocation facilities without limiting geographic deployment and other parameters. Automotive manufacturers and automotive radar manufacturers work closely together as a matter of necessity to coordinate standards for operation of SRRs so that motor vehicles of different manufacture can utilize SRR technology without interference even in close traffic conditions. This would not be true if unspecified radiolocation systems were permitted to operate generally in the 77-81 GHz band.

IV. The Commission Should Permit Automotive Radars to Operate at 77-81 GHz by Amendment of Section 15.253 of the Commission's Rules.

15. In summary, Bosch strongly recommends that the Commission address the developed uses of the 77-81 GHz band, either by issuing a Further Notice in this proceeding or by withholding action until a Petition for Rule Making is filed seeking modification of Section 15.253 of the Commission's rules to include the 77-81 GHz band. There are a number of uses that are mobile and ubiquitous, including FOD radars, automotive radars and the Amateur Radio Service in this band, and it will be necessary to take into account any regulatory requirements necessary to protect millimeter-wave RAS observatories from interference as well. Bosch has conducted extensive discussions with representatives of the Amateur Service and has worked diligently with the Radioastronomy Service to understand the EMC issues and to arrive at compatibility in

this band. Only by allowing all parties to develop standards and practices cooperatively can this process result in the maximum level of spectrum efficiency for all concerned. Bosch is of the view that there can be sufficient compatibility among RAS, automotive SRRs, Amateur Radio and FOD radars in this band, but FOD radars should not be authorized without compatibility studies and the ascertainment and specification of operational and technical parameters for those radar systems that are not proposed in this *Notice*. The Commission should issue a Further Notice in this proceeding proposing to authorize automotive SRRs under Part 15 in the range 77-81 GHz and FOD Radars at 78-81 GHz under Part 90, following compatibility analyses prepared together with the Radioastronomy and Amateur Radio communities.

Therefore, the foregoing considered, Robert Bosch, GmbH, respectfully requests that the Commission take no final action in this proceeding in response to the Notice, but instead to issue a Further Notice in this proceeding incorporating the broader relief requested herein, thus to insure maximum spectrum efficiency and frequency re-use.

Respectfully submitted,

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February 8, 2012

National Radio Astronomy Observatory

Electronics Division Technical Note No. 219

Measurements of Automotive Radar Emissions received by a Radio Astronomy Observatory

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December 8, 2011

Abstract

The radio astronomy community within the United States and elsewhere around the world enjoys a high degree of radio spectrum protection in the 77 to 81 GHz region. The global automotive industry, motivated by recent European Commission mandates, is developing short range radar systems to operate in this band to address issues of safety; the spectrum 76-77 GHz has already been in use since 1999 for Long Range Radars (Adaptive Cruise Control). In an attempt to understand the impact upon radio astronomy observations, measurements sponsored by the National Science Foundation were performed on 2 different short range vehicular radar systems. The radar systems were provided by Robert Bosch GmbH and by Continental Corporation and were operated at separation distances of 1.7 km and 26.9 km from the University of Arizona's 12 Meter millimeter wave telescope[1]. Measurements results are reported, and compared with the recommendations in ITU-R RA.769-2.

1 Introduction

Portions of the 76-81 GHz spectral region are allocated to the Radio Astronomy Service (RAS) in the United States and worldwide either on a primary or a secondary basis, and radio observatories that observe in this part of the spectrum currently enjoy interference-free operations. The worldwide automotive industry is developing various car radar systems for safety and operational purposes that would operate in this band on an unlicensed basis. In an effort to understand the impact that such systems may have on radio astronomy installations, measurements of the emissions of representative radar units were made at the University of Arizona's 12 Meter (12-M) Telescope[1] located at Kitt Peak, Arizona in October, 2011. Emissions of two different automotive radars, manufactured by Robert Bosch GmbH and by Continental Corporation were measured. These units were mounted temporarily on the vehicle; in production, they are expected to

[1] The 12-M Telescope at Kitt Peak is operated by the Arizona Radio Observatory (ARO) of Steward Observatory, at the University of Arizona.

be placed within a vehicle's bumper. The transmitters were first located at a nearby car park 1.7 km distant, and secondly at a site 26.9 km away at Sells, AZ. The 12-M telescope receiver was tuned to a center frequency of 79 GHz (Continental radar) or 77.8 GHz (Bosch radar). The car radars were used in an FMCW mode, in which the CW signal is swept at a constant rate from 77.03 to 78.58 GHz, a total bandwidth of 1550 MHz (Bosch radar) or from 78.93 to 79.1 GHz, a total bandwidth of 170 MHz (Continental radar).

The received signal was observed using the standard radio astronomical filter bank spectrometer covering a 500 MHz band centered at the radar's mid frequency, with 2 MHz resolution. In normal operation the 12-M Telescope uses a Cassegrain optics system. However, for this test we used the 12-M Telescope receiver and horn feed, but the beam of the feed was redirected from the subreflector by mounting a plane mirror in front of it . The main reflector of the 12-M Telescope thus did not play any part in these tests. With this arrangement the 12-M dish mount was used to point the beam of the telescope feed at the radar to achieve a "line of sight" path from the radar to the telescope receiver. Figure 1 shows the arrangement; a photograph of the plane reflecting mirror in front of the subreflector is shown in Figure 2. The redirected beam is offset by approximately 43.4 degrees in azimuth and 80 degrees in elevation away from the normal 12-M antenna pointing direction.

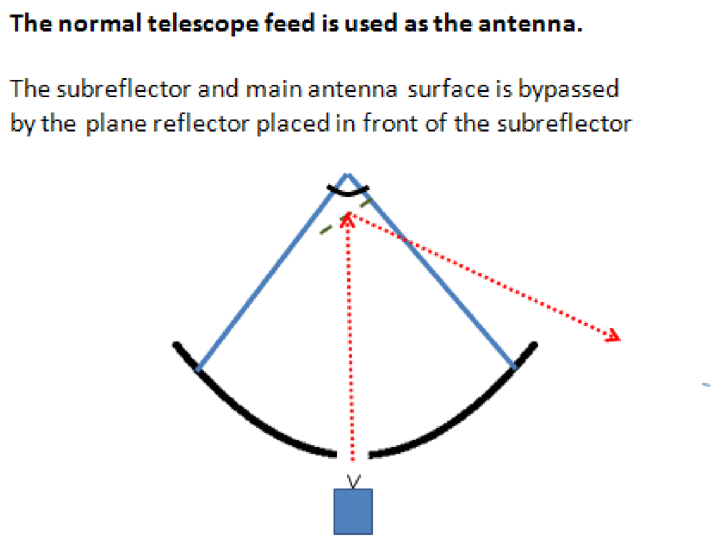

Figure 1 The normal secondary focus receiver and Cassegrain feed is used independently of the main 12-M reflector. An inclined plane reflector is placed in front of the subreflector, redirecting the beam from the receiver to the ground, rather than utilizing the main dish surface.

Figure 2 The inclined plane reflector in front of the subreflector redirects the signal received from the radar transmitter directly into the receiver, eliminating the use of the main antenna reflector. In the configuration shown, the signal is being received from the ground.

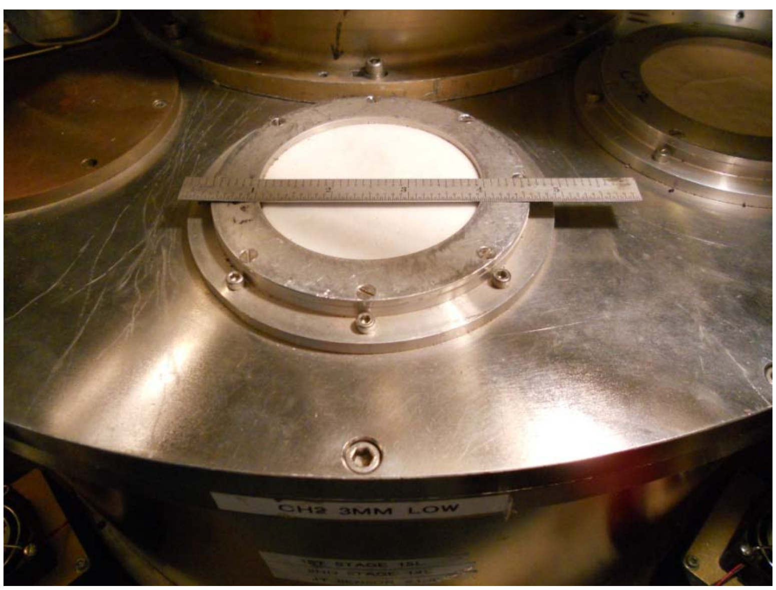

Figure 3 The 3-inch diameter window in the receiver Dewar is positioned immediately above the feed horn and SIS (superconductor-insulator-superconductor) mixer of the receiver used for these measurements. The signal is normally focused by the main 12-m diameter reflector onto the subreflector and then into the receiver. For these measurements, the signal from the radar is received directly, without utilizing the subreflector or the main 12-m antenna reflector at all.

The window above the SIS (superconductor-insulator-superconductor) mixer receiver in its Dewar is shown in Figure 3. The receiver itself is cooled to 4 K.
More details of the telescope's receiver optics can be found in the references below by Payne et al.

2 Beamwidth of the receiver feed

The beamwidth of the 12-M receiver feed was measured in a separate test in which the radar was located 1.7 km away in the parking lot of the 90" Steward Telescope (NB this is not a public parking area). With this line of sight path the radar signal was strong enough to easily determine the beamwidth in the vertical and horizontal directions by scanning the receiver beam across the radar source. The beamwidth was symmetrical in the vertical and horizontal directions with full-width half power of 3.1 +/- 0.1 degrees. Assuming a Gaussian beam this beamwidth corresponds to a gain of 35.8 +/- 0.2 dBi.

The main beam gain of a 12-M antenna, such as the mm-wave radio telescope at Kitt Peak, is about 78 dBi at 79 GHz, so the feed antenna used for these measurements is equivalent to a -42 dB sidelobe of such an antenna.

3 Receiver and system noise temperatures

The receiver noise temperature was calculated from the "Y factor" measurement using liquid nitrogen cooled absorber "cold" load (80K) and an absorber vane at ambient temperature (301K). The receiver noise temperatures were determined to be 75K and 108K respectively for the vertical (channel 1) and horizontal (channel 2) polarization channels of the receiver. For tests of the radar the system temperatures were assumed to be equal to the receiver noise plus the ambient temperature (301K) since the beam was always filled by the ground and atmospheric radiation when pointing at the radar; atmospheric attenuation over the 26.9 km path was some 4 dB, so atmosphere alone would have contributed some 180 K to the total receiver system noise over that path. We assume ground temperature and the atmospheric temperature over this near-horizontal path both equal to the ambient temperature.
A check of the receiving system was made by observing the Sun at an elevation of 10 degrees. This was the highest elevation at which the offset beam could be pointed and was reached with the 12-M dish mount pointed at the zenith. The "vane" calibrated temperatures measured on the sun were 167K and 170K respectively for the 2 channels. These values are close to the expected value of 168K above the atmosphere derived from the radio flux density of 10150.10^{-22} W/m^2/Hz at 79 GHz (see Benz, reference below). To first order the vane calibration measurement corrects for the attenuation of the atmosphere, so this is excellent agreement. These solar observations are completely consistent with the measured receiver temperatures and the feed antenna gain.

4 Beam polarizations

The receiver consists of two independent channels, sensitive to orthogonal linear polarizations. The two polarizations are split via a grid of parallel fine wires, which transmits one polarization and reflects the other. Allowing for the orientation of the plane mirror in front of the subreflector, one of these channels is sensitive only to vertical linear polarization, the other to horizontal. Tests of the polarization were made with the radar at 1.7 km. With the radar transmitting its normal vertical polarization mode, the signal was very strong in channel 1 and at least 30 dB weaker in channel 2. When the radar was physically rotated by 90 degrees the signal appeared in channel 2 and was more than 30 dB down in channel 1.

5 Measurements of the radar at 1.7 km

Figure 4 and Figure 5 show the signals received from, respectively, the Continental radar with a nominal 200-MHz bandwidth, and the Bosch radar with a nominal 1550-MHz bandwidth.

In Figure 4, the emission shows two distinct features

(a) A plateau of emission approximately 170 MHz wide, and
(b) A spike of emission at the high frequency end of the overall emission.

In both figures, the vertical axis is in units of antenna temperature, ultimately calibrated against the hot (ambient) and cold (liquid nitrogen) loads that had previously been measured in front of the receiver. For reference, 1000 K of antenna temperature, with a receiver antenna of gain 35.8 dBi, corresponds to an spfd (spectral power flux density) at the receiver of -115.0 dBW/m^2/MHz.

From Figure 4, the plateau of emission is 968 K, corresponding to an spfd at the receiver of -115.1 dBW/m^2/MHz. Integrating over the 170 MHz of emission, this becomes a power flux density (pfd) of -92.8 dBW/m^2 at the receiver. Allowing for a free space path and an atmospheric attenuation of 0.3 dB, this corresponds to a total emitted power (EIRP) at the transmitter, just within the plateau of emission, of +13.0 dBm. Expressing this as a spectral EIRP at the sensor, this is -9.3 dBm/MHz. This is in excellent agreement with the -9 dBm/MHz measured by the sensor manufacturer, and which represents the maximum power allowed by the European Norm EN 302 264.

The spike of emission in Figure 4 has a peak brightness temperature of 5982 K, as measured in a 2-MHz filter channel. Excluding the plateau of emission, that corresponds to a received spfd of -107.2 dBW/m^2/MHz. This spike of emission is only visible in this pre-series sensor and would be removed for the production version of the sensor. It is not considered further here.

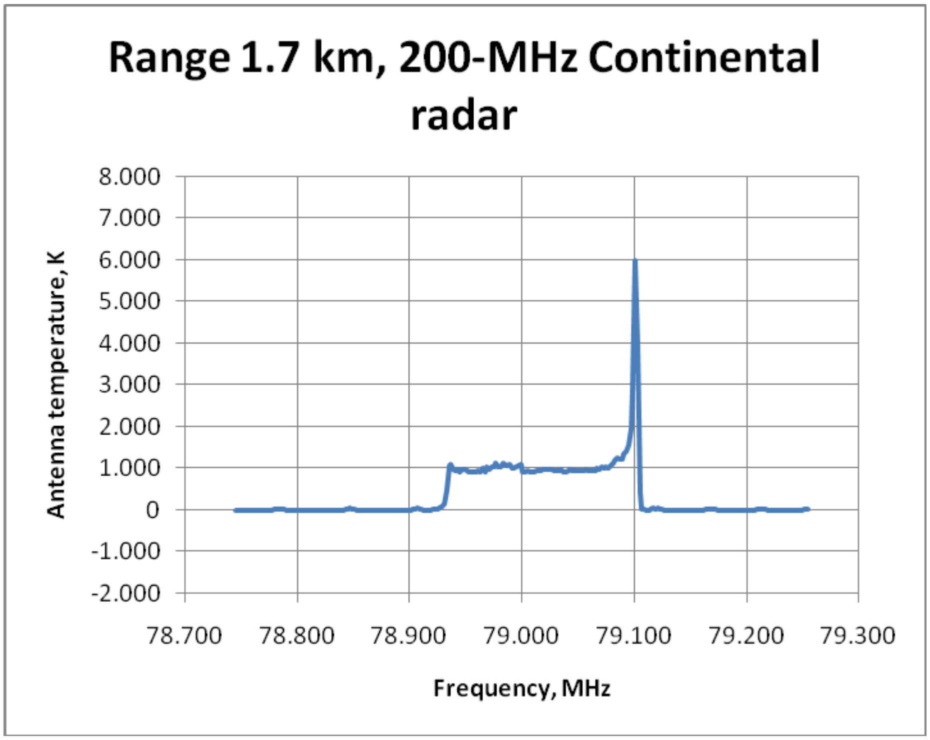

Figure 4 The received signal from the Continental radar, with a nominal 200-MHz bandwidth, at a distance of 1.7 km. See text for comments.

Away from the main emission of the transmitter, say +/-150 MHz in Figure 4, there is some residual response, but at a much lower amplitude of about 11 K. This is some 27 dB down on the peak emission of 5892 K. The theoretical rms receiver noise fluctuations for this observation are only ~0.084 K.

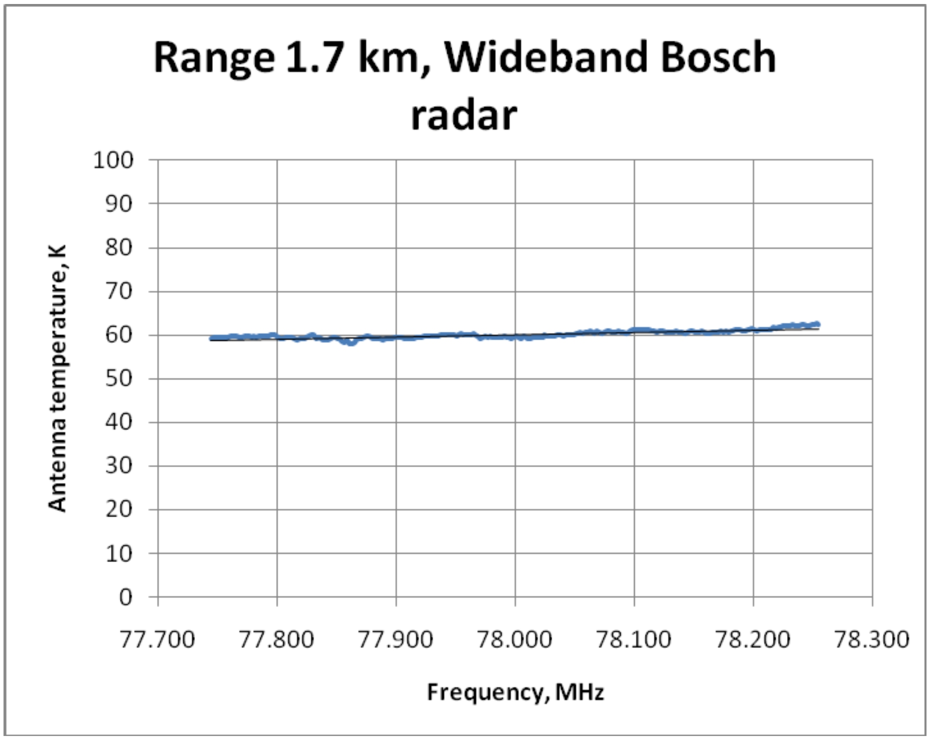

Figure 5 The signal received from the 1.7 km distant Bosch wideband radar, centered o n 77.8 GHz. Although the transmitted signal is nominally 1550 MHz wide, the receiver only sees the central 512 MHz of that band.

In Figure 5, showing the Bosch radar, the central 512 MHz of emission centered at 77.8 GHz, has a mean brightness temperature of 60.1 K. The corresponding spfd of this at the receiver is -127.2 dBW/m^2/MHz, with a received pfd (assuming 1550 MHz emission bandwidth) of -95.3 dBW/m^2. Again, allowing for the inverse square path loss and 0.3 dB of atmospheric attenuation, that corresponds to an effective isotropic radiated power (EIRP) of 13.7 dBm at the transmitter.

6 Measurement of the radar EIRP at 27 km.

The primary tests of the radar were made by driving to the seldom used airport at Sells, AZ. which is 26.9 km away and is in clear view of the 12-M telescope. The receiver beam was pointed at this location using angles computed from the GPS-determined locations of the radar at Sells and the 12-M telescope. After clearly detecting the radar in the spectrum of channel 1 the beam position was checked and found to be very close to the peak which was reached with a very small adjustment in elevation. The observed spectra are plotted in Figure 6 and Figure 7 in units of degrees Kelvin of antenna temperature. Each spectrum is the difference of the spectra taken for 30 seconds with the radar turned on followed by 30 seconds with the radar emission suppressed by covering its antenna with layers of absorber. This sequence may be repeated and the results averaged, in order to improve signal-to-noise ratio. The peak in the spectrum at 79.1 GHz, as already seen with the measurements at 1.7 km, is due to an initial low scan rate of the FMCW and is not expected in normal automobile radar operation. As before, the EIRP can be estimated from the integrated power over the 170 MHz width of the FMCW after correcting for the free space and atmospheric path loss and receiver antenna gain.

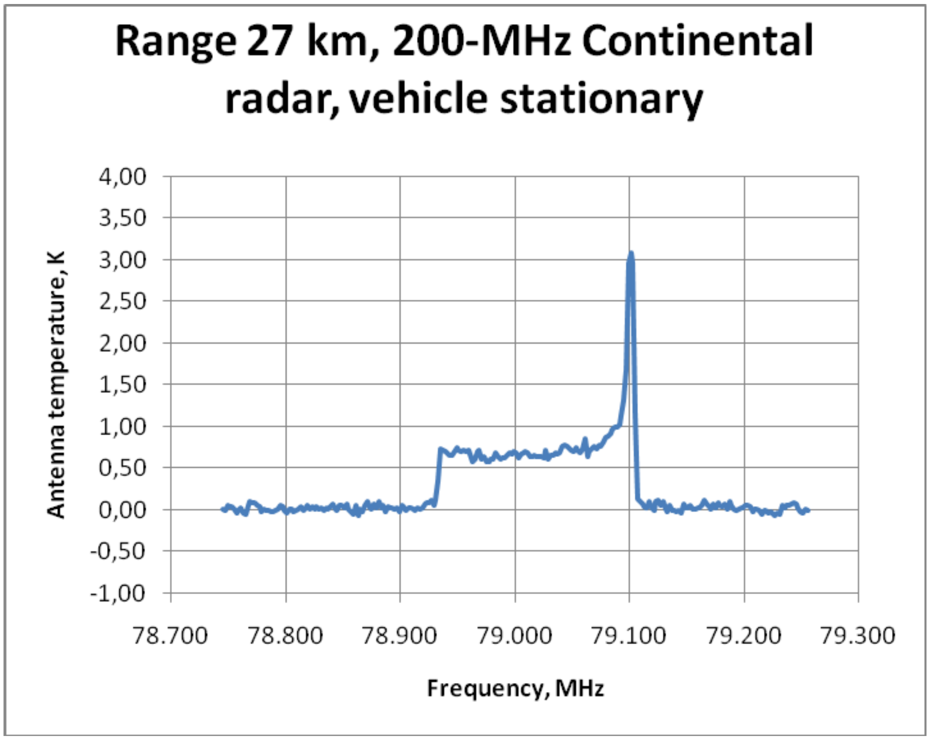

Figure 6 At a range of 26.9 km, this is the emission seen from the Continental 200-MHz radar, with the vehicle stationary. The average plateau of emission has a brightness of 0.68 K, while the high frequency spike is 3.08 K. The noise in the spectrum on either side of the emission is 0.038 K, close to the theoretical receiver noise of 0.036 K.

Figure 6, with the vehicle at 26.9 km and stationary, the received spfd of the plateau of emission is -146.7 dBW/m^2/Hz; the spike of emission is some 6.6 dB stronger. The received pfd of the plateau is -124.4 dBW/m^2. Allowing 99.6 dB for the free space path loss and 4 dB for atmospheric attenuation, the estimated EIRP of the plateau of emission is 9.2 dBm.

From Figure 7, with the vehicle in motion, the observed spfd of the plateau is -144.7 dBW/m^2/Hz, with the spike stronger by a similar factor. The received pfd of the plateau is -122.4 dBW/m^2, with an estimated EIRP for the plateau component of 11.2 dBm. While in motion, the antenna remained in an orientation facing the distant receiver. The received signal was averaged over 30 seconds.

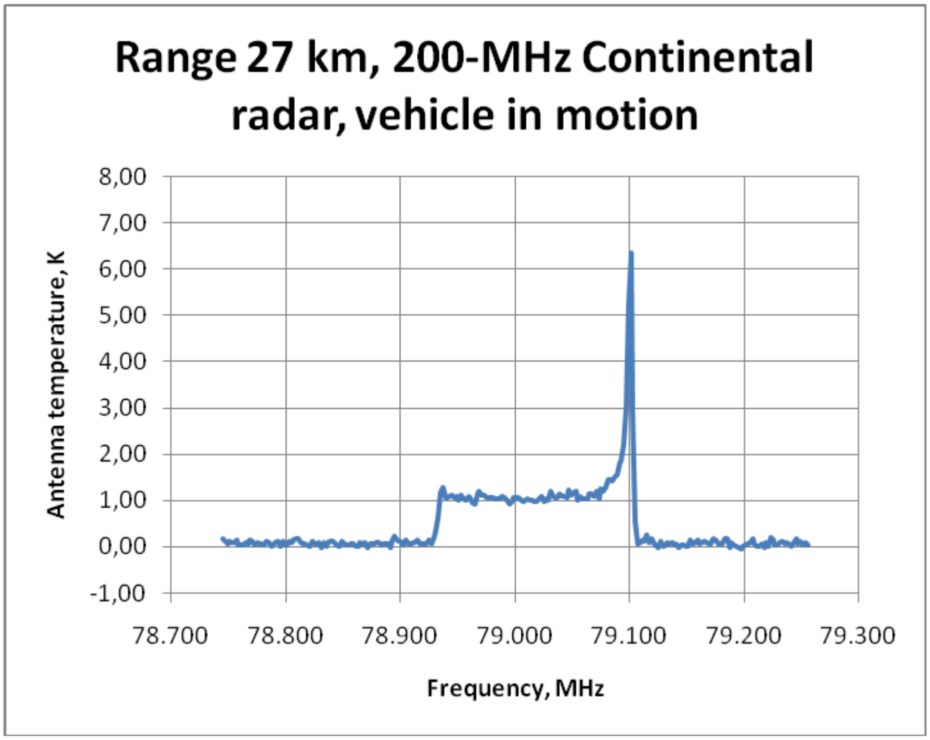

Figure 7 At a range of 26.9 km, the emission from the Continental 200-MHz radar, with the vehicle in motion. The plateau of emission has a brightness of 1.07 K, and the high frequency spike 6.4 K. The receiver noise on either side of the emission is 0.053 K, very close to the theoretical receiver noise of 0.049 K.

Figure 8 shows the observed emission from the 800-MHz Continental radar, with the vehicle in motion. The mean brightness of the observed emission at the range of 26.9 km is 0.41 K, although only the central 500 MHz of the 800-MHz spectrum are seen in the receiver. This corresponds to an observed spfd at the receiver of -148.8 dBW/m^2/MHz, with a pfd of -119.8 dBW/m^2. With the free space loss and 4 dB of atmospheric attenuation, this corresponds to an EIRP of 9.2 dBm.

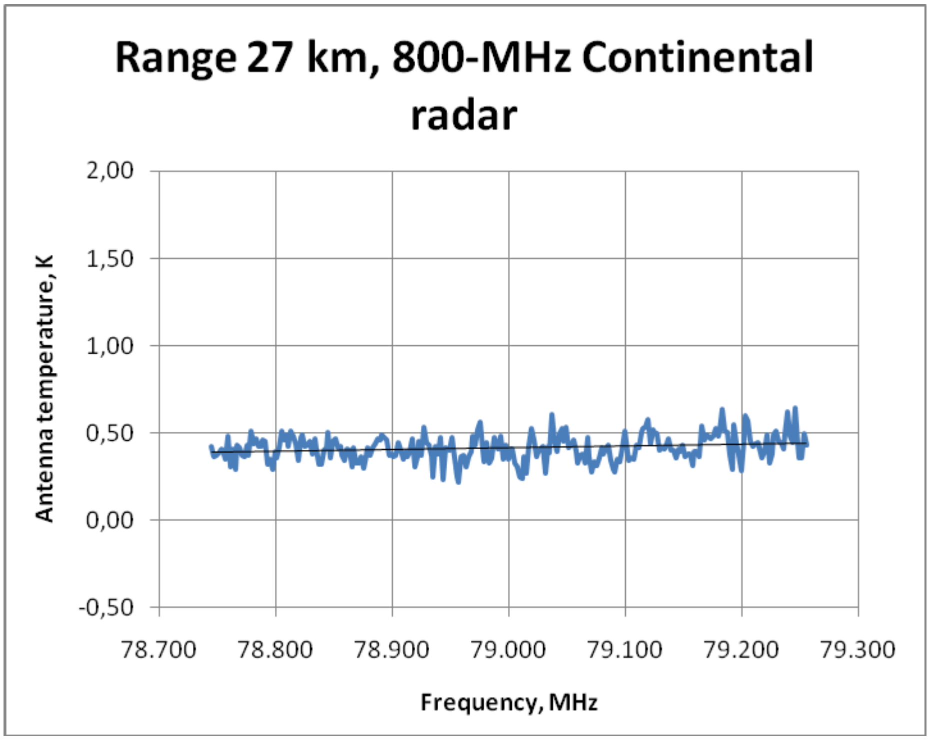

Figure 8 Range 26.9 km, observed emission from the Continental 800-MHz radar, with the vehicle in motion. The plateau of emission has a brightness of 0.41 K, although only the central 500 MHz of the 800 MHz emission spectrum are observed.

7 Summary of results

Table 1 Summary of Measurements

Fig	**Radar**	**Tb peak** K	**Tb plateau** K	**Prx** dBm	**Meas. Range** km	**Free space loss** dB	**Atm. Atten** dB	**Pfd** dBW/ m^2	**Spfd** dBW/ m^2/ MHz	**EIRP** dBm	**Avoid. Zone radius** km
4	Cont.200 Stationary	5982	968	-86.4	1.7	135.0	0.3	-92.8	-115.1	13.0	39
5	Bosch.WB Stationary	-----	60.1	-88.9	1.7	135.0	0.3	-95.3	-127.2	10.5	15
6	Cont.200 Stationary	3.08	0.68	-118.0	26.9	159.0	4.0	-124.4	-146.7	9.2	30
7	Cont.200 In motion	6.36	1.07	-116.0	26.9	159.0	4.0	-122.4	-144.7	11.2	34
8	Cont.WB In motion	-----	0.41	-113.4	26.9	159.0	4.0	-119.8	-148.9	13.7	25
-	**RA.769 1 MHz bw spectral line threshold**	-	-		-	-	-	-	**-148**	-	-

Notes on columns in above table:

Fig: The figure number in this document, from which the data in each row of the table were derived.

Radar: A description of the specific automotive radar. "Cont." means the radar provided by the Continental Corporation, and "Bosch" by Robert Bosch GmbH. "200" means a nominal bandwidth of 200 MHz (in fact 170 MHz) and "WB" means the wideband radar with a nominal bandwidth of 800 MHz (Continental) or 1550 MHz (Bosch).

Tb(peak) K: The antenna temperature in degrees K measured for the peak of emission found at 79.1 GHZ, as seen within a 2-MHz filter channel. This is for reference, but is not used in the subsequent calculations.

Tb(plateau) K: The antenna temperature in degrees K measured for the plateau of emission, excluding any isolated peaks, as seen within 2-MHz filter channels. The remaining columns in this table are based on this plateau of emission, not on the stronger peak at 79.1 GHz.

Prx: The power received, dBm. Calculated from Tb plateau .k. B, with k Boltzman's constant = $1.38.10^{-23}$, and B the bandwidth in Hz. For "Cont 200" the bandwidth is 170 MHz, for Bosch WB 1550 MHz, and for Cont.WB 800 MHz.

Meas. Range km: The line-of-sight distance, in km, between the automotive radar and the receiver used for these measurements.

Free space loss dB: This is the attenuation introduced by the free-space Range (km) given in the adjacent column, for isotropic transmit and receive antennas. This is calculated from $20.\log(4.\pi.d/\lambda)$, with d the distance in meters and λ the wavelength in meters, and does not include atmospheric attenuation.

Atm. Atten dB: This is the computed additional attenuation introduced by the atmosphere at this frequency, for the corresponding line-of-sight distance given in the "Range" column. A value of 0.15 dB/km is taken.

Pfd dBW/m^2 : This is the power flux density, integrated over the assumed transmitter bandwidth, of the total emission from the respective radar, at the receiver. Units dBW/m^2. This includes *only the plateau of emission*, not any isolated spikes within the spectrum. The receiver antenna gain of 35.8 dBi is taken into account in this calculation.

Spfd dBW/m^2/MHz: The spectral power flux density at the receiver, in units of dBW/m^2/MHz. This is derived from the previous column using (where possible) the measured bandwidth of emission, or by an assumed transmitter bandwidth.

The last line of the table gives the threshold spfd for interference taken from Table 2 in ITU-R RA.769-2, converting from “per Hz” into “per MHz” units.

EIRP: The derived effective isotropic radiated power (EIRP) at the transmitter, based on the received pfd shown in a previous column. Units of dBm. This is calculated from
EIRP = power_received + path loss + atmos.loss – recv_ant_gain, with
power_received from column 5 of this table,
path_loss from column 7,
atmos.loss from column 8,
and with *recv_ant_gain* = 35.8 dBi.

Avoidance Zone radius: Obtained by scaling the 1.7-km or the 26.9-km measurements to give the minimum distance from the radio telescope that would be necessary for a single transmitter, mounted on a single vehicle, to give a level of interference at or below the threshold specified in ITU-R RA.769, which is defined for a 0 dBi receiving antenna gain. In calculating the avoidance zone radius, an atmospheric attenuation of 0.15dB/km has been added to the normal free space inverse square distance path loss. This distance is then calculated from the difference between the observed spfd (column 10, Table 1) and the RA.769 value for spfd (last row, column 10), with the corresponding distance corresponding to this differential loss taken from Figure 9.
This is included purely for illustrative purposes. For multiple transmitters on a given vehicle, and for more than one vehicle in view of the telescope, the avoidance zone radius would be correspondingly increased. Mitigation factors such as any terrain shielding, orientation of the transmitter antenna with respect to the observatory, or attenuation of the transmitter if mounted behind the vehicle bumper have not been taken into account, and would tend to reduce the avoidance radius.

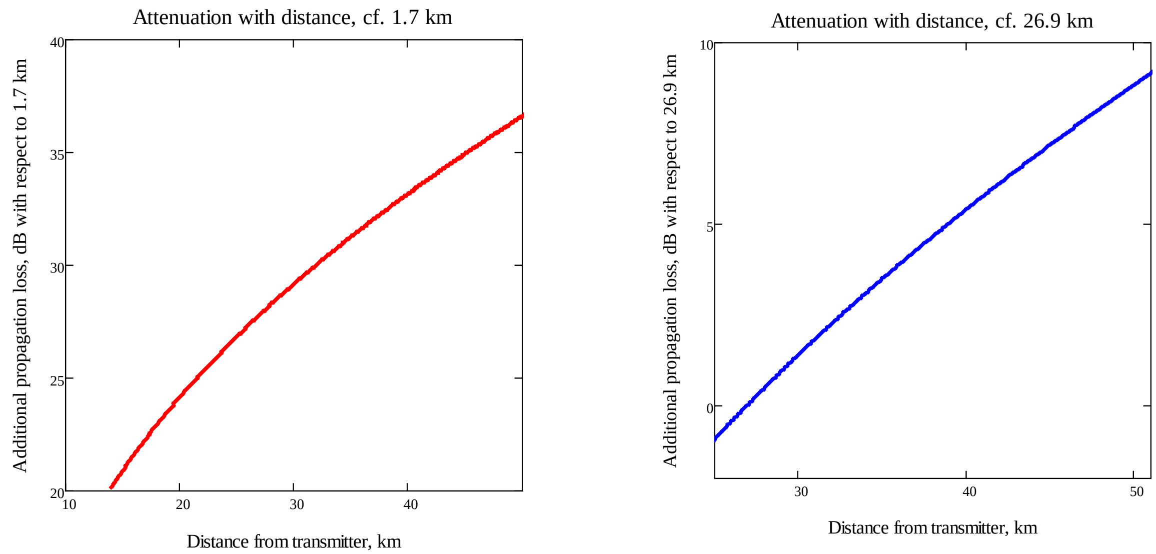

Figure 9 The extra propagation loss vs. distance, compared to a distance of 1.7 km (left) or 26.9 km (right), including both inverse square of distance free space loss and 0.15 dB/km of atmospheric attenuation.

8 Comparison with ITU-R RA.769.

The measured values of Table 1 above can be compared to the threshold interference levels defined in ITU-R RA.769. That recommendation contains separate recommendations for the case of broadband interference (Table 1 of RA.769, "continuum"), or for narrow-band (Table 2 of RA.769,"spectral line") interference. In the current context, allowing for the dilution of the 170-MHz or 1550-MHz bandwidth of the interfering transmitter signal over the 8 GHz receiver bandwidth as defined in RA.769, the different interference thresholds are within a few dB of each other.

8.1 Spectral Line Threshold

First we consider the spectral line case. Table 2 of ITU-R RA.769-2 gives a threshold level of interference detrimental to radio astronomy spectral-line observations in this frequency band of -208 dBW/m^2/Hz, equivalent to -148 dBW/m^2/MHz. As seen in Table 1 above, by chance most of the measurements described here give an spfd at a distance of 26.9 km within a few dB of this limit. The rightmost column of Table 1 above gives the necessary avoidance zone radius in order that the corresponding transmitter measured here does not produce an interference level at the radio telescope in excess of the spectral line threshold defined in RA.769. Note this is purely for illustrative purposes, and applies to a single transmitter on a single vehicle.

8.2 Continuum Threshold

The corresponding continuum spfd threshold interference level, taken from ITU-R RA.769-2 Table 1, is -228 dBW/m^2/Hz, equivalent to -168 dBW/m^2/MHz. This is 20 dB more stringent than the spectral line case discussed above. However, the interfering emission in this case must be averaged over 8 GHz. For example, if emission from a single Continental 170-MHz bandwidth radar were diluted over 8 GHz, the average spfd per MHz would be reduced by 8000/170 = 16.7 dB, which by chance is close to the 20 dB greater stringency of continuum interference threshold.

Note that, if there are several transmitters on a given vehicle *on different frequencies*, then although the spectral line threshold spfd (in any 1 MHz band) may remain unchanged, nevertheless the average spfd within an 8-GHz band, as defined by the RA.769 continuum threshold, would increase correspondingly. Table 2 below summarizes the comparison between our measurements and the threshold for interference to continuum observations defined in RA.769-2.

Table 2 Comparison of Measurements with RA.769 Continuum Threshold

Fig	**Radar**	**Tb plateau** K	**Meas. Range** km	**Atm. Atten** dB	**Transmitted bandwidth** MHz	**Spfd, diluted over 8 GHz band** dBW/m^2/MHz	**Avoidance Zone radius** km
4	Cont.200 Stationary	968	1.7	0.3	170	-131.8	48
5	Bosch.WB Stationary	60.1	1.7	0.3	1550	-134.3	41
6	Cont.200 Stationary	0.68	26.9	4.0	170	-163.4	38
7	Cont.200 In motion	1.07	26.9	4.0	170	-161.4	43
8	Cont.WB In motion	0.41	26.9	4.0	800	-158.9	51
-	**RA.769 8 GHz bw continuum threshold**	-	-	-		**-168**	-

Table 2 Comparison of the measurements with the spfd threshold of interference for continuum observations, as defined in Table 1 of RA.769-2

Notes on columns in above table:

Fig: The figure number in this document, from which the data in each row of the table were derived. Same as Table 1.

Radar: A description of the specific automotive radar. “Cont.” means the radar provided by the Continental Corporation, and “Bosch” by Robert Bosch GmbH. “200” means a nominal bandwidth of 200 MHz (in fact 170 MHz) and “WB” means the wideband radar with a nominal bandwidth of 800 MHz (Continental) or 1550 MHz (Bosch). Same as Table 1.

Tb(plateau) K: The antenna temperature in degrees K measured for the plateau of emission, excluding any isolated peaks, as seen within 2-MHz filter channels. The remaining columns in this table are based on this plateau of emission, not on the stronger peak at 79.1 GHz. Same as Table 1.

Meas. Range km: The line-of-sight distance, in km, between the automotive radar and the receiver used for these measurements. Same as Table 1.

Atm. Atten dB: This is the computed additional attenuation introduced by the atmosphere at this frequency, for the corresponding line-of-sight distance given in the "Range" column. A value of 0.15 dB/km is taken. Same as Table 1.

Transmitted bandwidth: This is the actual bandwidth occupied by the emissions from each transmitter. For multiple transmitters on different frequencies, this figure would have to be correspondingly increased.

Spfd, diluted over 8 GHz band: This is derived from the column **Spfd** in Table 1, but allowing for the dilution of the transmitted signal over the 8 GHz receiving band defined by RA.769. An amount *10.log(B/8000)* is added to the values tabulated under **Spfd** in Table 1, with B corresponding to the bandwidth of the radar emission in MHz, given in column 6. The last row in this table contains the spfd threshold of -228 dBW/m^2/Hz taken from Table 1 of RA.769-2, equivalent to 168 dBW/m^2/MHz.

Avoidance Zone radius: Exactly as in Table 1, but for the RA.769 continuum threshold. This distance is calculated from the difference between the observed spfd given in column 7, **Spfd diluted over 8 GHz**, and the RA.769 value for continuum spfd threshold (last row, column 7), with the distances corresponding to this differential loss derived as before from Figure 9.
As with Table 1, this is included purely for illustrative purposes. For multiple transmitters on a given vehicle, and for more than one vehicle in view of the telescope, the avoidance zone radius would be correspondingly increased. Mitigation factors such as any terrain shielding, orientation of the transmitter antenna with respect to the observatory, or attenuation of the transmitter if mounted behind the vehicle bumper have not been taken into account, and would tend to reduce the avoidance radius.

9 Estimated errors

Most of the received spectra were taken with the radar at a height of 1.6m at a fixed location. Tests made with the vehicle moving over a paved surface in Sells resulted in an increase in signal strength of about 2 dB. This change was most likely the result of a change in the ground reflection which interferes with the signal via the direct path. For example, a ground reflection coefficient magnitude of 0.3 (-10 dB) results in a variation of about +/- 2 dB depending on the reflection phase, which depends on the height of the radar and the elevation angle of the line of sight to the receiver. Uncertainty in the atmospheric attenuation is another source of error. The 225 GHz “tipper” radiometer at the 12-M telescope was used to derive a zenith precipitable water vapor content of 4.3mm, which corresponds to 11% relative humidity at 300K. Using the curves of Shambayati the attenuation at 79 GHz is estimated to be 0.1 dB/km for the water vapor and 0.04 dB/km for the dry atmosphere for a total of 4 dB for the 26.9 km path. The uncertainty in this estimate is about +/- 1 dB. Using the ITU-R P.620 recommendation, for a high dry site the total atmospheric attenuation would be about 0.135 dB/km, in good agreement with Shambavati. Another estimate was obtained by measuring the contribution of the atmosphere to the receiver noise. At an elevation of 3 degrees the atmosphere contributed 100K which corresponds to 4.8 dB of attenuation. If we assume a scale height for the water of 2 km then the path length at 3 degrees is 38 km, so that the loss for a horizontal path of 26.9 km is estimated by this alternate method to be 3.5 dB.

The estimates of EIRP made at different distances are in quite good agreement. With the vehicle stationary, the estimated EIRP from 26.9 km of the plateau of emission from the Continental, 200-MHz radar is 9.2 dBm; however, the comparison with results when the vehicle were in motion suggest that this value may be artificially low, presumably because of ground reflections. With the vehicle in motion at 27 km, 11.2 dBm was derived. See Figure 6 and Figure 7. At 1.7 km, the corresponding estimate (Figure 4) is 13.0 dBm, some 1.8 dB greater. This difference of 1.8 dB might be attributable to an underestimate of atmospheric attenuation over the 27 km path, to different reflections from the road and nearby terrain, or to differences in orientation of the transmitter antenna with respect to the receiver at Kitt Peak. The elevation angle towards the Kitt Peak receiver from the 1.7 km distant site was approximately -6 degrees, while from the Sells airport was approximately +10 degrees. The spfd derived here from the measurements at a distance of 1.7 km of the Continental (170 MHz) radar was -9.3 dBm/MHz, while the manufacturer measured -9.0 dBm/MHz. Considering the possible sources of error, the agreement with the manufacturer’s data, and between the different measurements at different distances reported here, is considered to be very good.

10 Conclusions

Tests performed with short range vehicular radar systems, operated at distances of 1.7km and 26.9 km from the University of Arizona’s 12 Meter millimeter wave telescope, demonstrated that these radars could have a significant impact upon radio astronomy observations in the 77 to 81 GHz region. A zone of avoidance of about 30 to 40 km around a mm-wave observatory would be needed, in order to keep interference from a single vehicle below the threshold defined in RA.769-2. Smaller zones of avoidance might suffice in areas without direct line of sight to the radio telescope and/or by taking some of the above mentioned mitigation factors into account. ITU-R RA.1272-1 specifically recommends that such zones be established around mm-wave astronomical observatories, following the procedure outlined in Recommendation ITU-R RA.1031-2.

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